THE EFFECT OF LARGE EXTERNAL STORES ON THE LOW SPEED LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A 60° DELTA WING AND FUSELAGE WITH STORES LOCATED ON THE LOWER SURFACE

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Master of Science in Aeronautical Engineering

By

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Approved:

Date Approved by Chairman: Oct 25, 1955

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LIST OF SYMBOLS

C_D	drag coefficient (drag/qS)
C_L	lift coefficient (lift/qS)
C_M	pitching moment coefficient (pitching moment/$\bar{c}$qS)
$\mathrm{C}\!\!\!\!\mathrm{L}$	center line
C_{L_α}	lift curve slope, $\frac{d\ C_L}{d\ \alpha}$
$C_{M_{C_L}}$	stability derivative, $\frac{d\ C_M}{d\ C_L}$
L/D	store fineness ratio (length/diameter)
P (hit)	probability of hit
V	free-stream velocity, ft./sec.
X_o	longitudinal distance from reference point to pitching-moment axis
X_1	longitudinal distance from reference point to centroid of induced lift on $\bar{c}/4$
X/D	ratio of store nose position to store diameter
b/2	wing semi-span, ft.
c	local wing chord, ft.
c'	mean geometric chord, ft.
$\bar{c}$	mean aerodynamic chord, ft.
c_ℓ	local wing lift coefficient, (lift/qS)
q	dynamic pressure, $(\rho V^2/2)$

w	jet-boundary-induced upwash velocity, ft./sec.
Λ	sweep angle of wing leading edge, degrees
α	model angle of attack, degrees
Δ	incremental variation of parameters
ε	tunnel blocking correction factor
η	wing spanwise station, tenths semi-span
ρ	mass density of air, slugs per cubic foot

LIST OF FIGURES

SUMMARY

This report is the result of an experimental low speed investigation made in the Georgia Tech nine-foot diameter wind tunnel to determine the effects of large external stores on the longitudinal aerodynamic characteristics of a 60° delta-wing type aircraft. The parameters studied were store fineness ratio (L/D = 8 and 12), store spanwise location (22, 40, 60 per cent semi-span), store chordwise locations (forward and aft on wing), store fuselage location (forward, mid, and aft on fuselage) for stores on the lower surface of the model.

The data for store positions on the fuselage show that the lift curve slope is insensitive to store fineness ratio. There is a decrease of C_{L_α} for all store locations on the fuselage, with the forward fuselage position resulting in the largest loss. The static stability increased with store fineness ratio and with store movement aft on the fuselage. The maximum lift was decreased inversely with store fineness ratio and aft movement on the fuselage. The minimum drag for mid-fuselage position was the smallest and for the forward fuselage position the L/D = 12 store had a smaller minimum drag, whereas the mid-fuselage position is the most favorable from a drag standpoint over the whole lift range.

The data for store positions on the wing show that the lift curve slope is insensitive to store fineness ratio. There is an increase in C_{L_α} for store movement towards the wing tip. The static stability increased with store fineness ratio and store movement towards the wing tip. The maximum lift was decreased inversely with store fineness ratio and the

largest loss of maximum lift was for the 40 per cent semi-span and forward wing positions. The minimum drag decreases with store movement towards the wing tip. The L/D = 8 store has smaller minimum drag for the 22 per cent semi-span and the L/D = 12 store has smaller minimum drag for the 60 per cent semi-span. Over the lift range the nearer the wing tip the more favorable the drag. All the results correspond to an effective Reynolds number of 3.37 million.

CHAPTER I

INTRODUCTION

With the high speed, high altitude requirements of our interceptors a large range of new problems has resulted. The Department of Defense in attempting to solve these problems in the most expeditious manner, consistant with money available, instituted the concept of Weapon Systems. The concept calls for a completely integrated system from the early warning net to the Air Defense Control centers for evaluation and target assignment to interceptor squadrons. The interceptor squadrons must have on alert the adequate fire power to destroy the target.

The probability of kill, P (kill), of the target has been stated by the Department of Defense to be of the form P (kill) = P (detect) x P (correct evaluation) x P (scramble) x P (target acquisition) x P (hit) x P (destroy). As each of the probabilities, P (), can not exceed unity it is seen that the maximum effort, consistant with time and money, must be put into maximizing the probability of kill and hence the defense of our nation against atomic and thermonuclear warfare. The one enemy plane that gets through may have a hydrogen bomb.

The fire power available today is of the air-to-air rocketry type with the one additional major armament, the small air-to-air guided missile. This small air-to-air guided missile and the rockets are usually carried as an interior weapon because of their own requirements. It is completely feasible that, in order to increase P (kill), one large step would be to make P (hit) x P (destroy) equal to unity. One way of doing this is with thermonuclear warheads, which would require large external rockets that have a large radius of destruction.

The effect of these large external stores on the weapon carrier will be very different from the small armaments of today. It is the object of this investigation to determine some of the low speed effects on a delta-wing type aircraft. The scope of this investigation will be limited to store chordwise location, spanwise location, fuselage location, and two fineness ratios. The investigation will be further restricted to the low speed effect of these parameters on lift, drag, and pitching moment.

The author has found that the unclassified literature on large external stores for delta wings is extremely limited. Comparisons were made where possible.

CHAPTER II

APPARATUS AND MODELS

The tests were conducted in the nine-foot-diameter wind tunnel[1] at Georgia Tech. The tunnel is of the single-return type having a closed circular jet vented to the atmosphere. Power source is a 200 horsepower synchronous motor driving a four-bladed variable pitch propeller. The wind velocity in the tunnel is controlled by adjustment of the propeller pitch with a maximum velocity of 150 miles per hour. The model was mounted on a three support system with the two main struts forward mounted on the mean aerodynamic chord quarter chord points and one strut aft mounted on an attach point in the fuselage. The model attitude was controlled by raising and lowering the aft strut. The forces and moments were measured by means of a six component electro-mechanical balance system.

The model used was a delta-wing fuselage combination plus two variable length, finned stores. A drawing of the assembled delta-wing model is shown in Fig.1.

The wing is a delta with a 60° sweep of the quarter-chord line. The wing span is 48 inches and has an aspect ratio of 1.73. The airfoil is an NACA 0009 with sections parallel to the plane of symmetry. The wing is constructed of laminated mahogany, with exception of the wing tips which are aluminum. The location of store mounting points and strut supports are shown in Fig. 2.

The fuselage is a body of revolution utilizing the ordinates of an NACA 64012 airfoil with an eighty inch chord. The body was cut at the point of maximum diameter (0.40 chord) and a cylindrical section of this diameter and length of twenty inches was added. The last 27.5 per cent chord was cut off to give a blunt base five inches in diameter to simulate the aft end of a jet aircraft. The basic airfoil was modified by substituting a straight taper from approximately the 60 per cent point aft to the trailing edge to eliminate the normal cusp of the 64 series airfoils. The fuselage was lathe turned from mahogany blocks in three sections and joined by glue and dowels. It was then cut along a horizontal plane of symmetry and contoured to receive the delta-wing in a symmetric mid-wing position. The two halves were fastened by two steel bolts. The upper fuselage was fitted with a quarter inch dowel which was received by a hole in the wing on the center line, fixing alignment of the wing and fuselage. A drawing and table of ordinates are shown in Fig. 3.

The stores were designed to allow for a variation of fineness ratio (8 and 12 being used) by changing a cylindrical center section which was made of three-inch outside-diameter aluminum tubing. The 37.5 inch radius ogive nose and cylindrical tail section were made of mahogany, and the fins in the tail section were made of one-eighth inch aluminum sheet. A drawing giving the details of the external store is shown in Fig. 4.

The pylons are made of laminated walnut, with an NACA 0009 airfoil section, a span of four and one-half inches (one and one-half store diameters), and a chord of seven and six-tenths inches. Each pylon-store assembly was attached to the wing by two steel bolts and bushings necessary to maintain one and one-half store diameters, measured from top of store to bottom surface of wing, below the wing. All fairings between the wing and pylon were made of plaster of paris.

The store was mounted on the pylon by glue and dowel to the 37.5 inch radius ogive nose and a steel bolt through the tail to the nose of the store in order to change the cylindrical center section and hence change the store fineness ratio. The nose extends 10.5 inches forward of the leading edge of the pylon.

The stores were located symmetrically with respect to the plane of symmetry. Two chordwise positions for each of three semi-span positions were tested. These positions are shown in Fig. 2.

A photograph showing the model in the tunnel with stores of L/D = 12 mounted at the 40 per cent semi-span position is shown in Fig. 5.

The wind tunnel boundary and blocking corrections are shown in the appendix.

CHAPTER III

PROCEDURE

The tare and interference effects were determined by using an image system. The wall corrections were determined in accordance with NACA Technical Note 2454[2] and are given in the appendix. It was necessary to make complete reruns in the -6 to +14 degree angle of attack range on all wing positions as the drag measuring component became very insensitive in this range. Because of a time limitation reruns on the fuselage were not made and the fuselage drag data given in this report is questionable.

The tunnel alignment corrections were obtained from the clean configuration data after gravity, tare and interference, and tunnel wall corrections were made. The investigation was conducted in a manner that allowed the effects of the parameters to be determined independently. The parameters studied were store spanwise location, chordwise location, fuselage location, and fineness ratio with stores located on lower surface of the model. There are many other parameters involved but only those above were investigated.

The model operating at a mean tunnel speed of 100 miles per hour was tested in nineteen configurations, the first being for the model in clean configuration. There were nine store positions (six on the wing and three on the fuselage) for each of the fineness ratios, eight and twelve. Three fuselage store positions were chosen: forward, aft and one position approximately at the 50 per cent chord of the fuselage.

The wing positions were chosen at semi-span stations of 22, 40 and 60 per cent respectfully and two chordwise locations for each semi-span location. The 22 per cent semi-span was dictated by the proximity of the fuselage and the 60 per cent semi-span by model structural considerations. The stores were mounted on top of the model in order to eliminate interference effects between stores and the three-point support system. Since the model is symmetrical, data taken at negative angles of attack simulates stores mounted on the lower surface of the model.

In all configurations the model was tested from -6 to +40 degrees with 4 degree increments between -6 and +12 degrees, two degree increments between 12 and 30 degrees, and one degree increments between 30 and 40 degrees. The lift, drag, and pitching moment were recorded at each angle of attack.

Previous tests[3] on wing-store (no fuselage) combinations showed no appreciable effect of Reynolds number over the range 2.45 to 3.97 million. The balance system is within the limits of one-tenth of one per cent of applied load[1] except for very small loads. The small load accuracy is limited by beam sensitivity which is approximately as follows:

Lift	0.10 lb.
Drag	0.05 lb.
Pitching moment	0.20 ft. - lb.

It should be noted that the error involved in the data reduction could be as much as twice the above since both the wind on and off errors are involved.

CHAPTER IV

RESULTS

The results of this investigation are shown in Figs. 6 through 17. To simplify the discussion the results have been divided into three groups, Fig. 6 is the clean model polar and Figs. 7 through 9 are concerned with lift, Figs. 10 through 14 with drag, and Figs. 15 through 17 with pitching moment. Figs. 7, 10, and 15 are representative curves comparing the clean model and clean model plus one store configuration. The fuselage positions are referenced by the position of the nose of the store with respect to the leading edge of the wing root chord as a ratio of store nose position to store diameter, X/D. The forward fuselage position corresponds to X/D = 3.03, the mid fuselage position to X/D = -3.60, and aft-fuselage position to X/D = -8.67.

The wing positions are referenced by the position of the nose of the store with respect to the local wing leading edge as a ratio of store nose position to store diameter, X/D. The forward chordwise wing position for all three semi-span positions corresponds to X/D = 3.5 and the aft chordwise wing positions to X/D = 0.

LIFT

Lift Curve Slope

Fuselage.--The store fineness ratio had no noticeable effect on the lift curve slope. The fuselage positions resulted in a decrease of lift curve slope when compared to model alone as shown in Fig. 8. The decrease was a constant for the forward and mid-fuselage positions, whereas the aft position approached the clean configuration.

Wing.--The store fineness ratio had no noticeable effect on the lift curve slope for the forward or aft wing positions. The lift curve slope, for the forward wing position, increases as the store is moved outboard along the span, and the increase in slope is very nearly linear, whereas in the aft wing position and 22 per cent semi-span location there is a decrease in lift curve slope and with movement of the store toward the wing tip the lift curve slope increases as shown in Fig. 8. It should be noted in Figs. 6 and 7 that the lift curve is linear to approximately $C_L = 0.4$; the slope then increases for the lift range $C_L = 0.4$ to 1.0. This non-linear range is due to the formation of a leading edge vortex caused by flow separation[4].

Maximum Lift

Fuselage.--The maximum lift is increased slightly for L/D = 12 for the forward fuselage position as shown in Fig. 9 and is decreased for the mid-fuselage and aft fuselage positions with the loss in maximum lift increasing with store movement aft. The L/D = 8 store reduced the maximum lift for all positions with the loss in maximum lift increasing with store movement aft on the fuselage.

Wing.--The maximum lift was the most sensitive for the forward wing position with the L/D = 8 resulting in less maximum lift as shown in Fig. 9. The maximum lift decreased on moving the store from 22 per cent semi-span to 40 per cent semi-span and then increased on moving the store from 40 per cent semi-span to 60 per cent semi-span. The maximum lift is not affected as much for the stores in the aft-wing position with the largest decrease occurring at the 22 per cent semi-span position as shown in Fig. 9.

DRAG

Minimum Drag

Fuselage.--The L/D = 12 store has a smaller minimum drag than the L/D = 8 for the forward and mid-fuselage positions whereas the aft position has nearly the same minimum drag for either store as shown in Fig. 11. This result is in direct conflict, except for aft-fuselage position, with data from an unpublished thesis with stores mounted in the same positions but on top of the fuselage[5]. No reruns were made of fuselage positions, therefore, as explained previously, this data is questionable.

Wing.--The minimum drag for the L/D = 12 store decreases with movement towards the wing tip as shown in Fig. 11 for both chordwise positions. The minimum drag for the L/D = 8 store did not follow any trends. The L/D = 8 store has a smaller minimum for 22 per cent semi-span for both forward and aft-wing positions and the minimum drag for the L/D = 12 store is smaller for 60 per cent semi-span and both forward and aft-wing positions.

Drag Polars

Fuselage.--The increase in incremental drag for the forward and mid-fuselage position varies inversely with store fineness ratio for

C_L = 0 to 0.3 and for C_L = 0.3 to 0.7 there is no effect of fineness ratio as shown in Fig. 12. The increase in incremental drag for the aft fuselage varies inversely with store fineness ratio for C_L = 0 to 0.7. The drag for the L/D = 12 store approaches the clean configuration at C_L = 0.7.

Wing.--

Forward --The L/D = 8 store has a smaller increase in drag for the forward wing position at the 22 and 40 per cent semi-span positions. The effect of fineness ratio at the 22 and 40 per cent semi-span is negligible above C_L = 0.6 (Fig. 13). The L/D = 12 store has a smaller increase in drag for the 60 per cent semi-span position. Above C_L = 0.45 the L/D = 12 store reduces the drag value less than that of the clean model.

Aft --The L/D = 8 store has a smaller increase in drag for the 22 per cent semi-span position. This effect can be seen in Fig. 14. The drag for the 40 per cent semi-span position showed no trend for change in fineness ratio. The drag showed a decrease in the lift range C_L = 0.2 to 0.5, and an increase for higher lift coefficients. The L/D = 12 store has a smaller increase in drag for 60 per cent semi-span position with no effect in fineness ratio above C_L = 0.45. Similar to the 60 per cent forward wing position the L/D = 12 store reduces the drag to a value less than that of the clean model for C_L = 0.5.

PITCHING MOMENT

Fuselage.--The static stability for $C_L = 0$ to 0.4 was observed to be sensitive to store fineness ratio and location. These effects can be seen in Fig. 16. For the forward fuselage position the L/D = 8 store reduced the static stability the most, however, the static margin was never positive with respect to 25 per cent chord. For stores located at mid and aft-fuselage positions the static stability is increased as the composite model center of pressure moves aft with movement of the stores towards the tail. In the aft position the L/D = 8 store increased the static stability the greatest. For $C_L = 0.6$ to 1.0 there is a loss of stability for all fuselage positions, however, never becoming unstable. This may be seen in Fig. 17.

Wing.--The static stability for $C_L = 0$ to 0.4 was observed to be sensitive to store fineness ratio and location. For the wing positions however, it was noted that the larger fineness ratio increased the stability. This result is in agreement with Ref. 3. The forward wing positions gave a decrease in stability with the 22 per cent semi-span location giving the largest reduction. At the 60 per cent semi-span position the L/D = 12 store increases the stability to a value slightly above that of the clean model.

For the aft wing position and the L/D = 12 store the model is more stable than model alone at all semi-span positions tested, while for the L/D = 8 store the 22 per cent semi-span was less stable and the 60 per cent semi-span is more stable than model alone. These effects can be seen in Fig. 16. The drag due to the stores produces a nose down moment. However, the stability is decreased in general. This result is believed to be due to the interference effect of the stores.

The forward wing positions reduced the stability the greatest in the lift range of $C_L = 0.6$ to 1.0, while the aft position and 60 per cent semi-span made the model more stable as can be seen in Fig. 17. This is in general agreement with Ref. 6. In general the static stability is increased with store fineness ratio and locations nearer the wing tip.

CHAPTER V

CONCLUSIONS

On the basis of the data obtained in this investigation, the following conclusions have been reached.

1. The store fineness ratio had no perceptible effect on lift in the low lift range (C_L = 0 to 0.4) and is not critical for drag for L/D = 8 or 12.
2. The lift curve slope increases with store locations nearer the wing tip, whereas the fuselage locations gave a decrease in lift curve slope.
3. The largest reduction in maximum lift is more critical for forward wing position and aft fuselage position.
4. The minimum drag for the stores on the fuselage is the mid-fuselage position. For the wing the minimum drag decreases with locations nearer the wing tip. The incremental increase in drag is decreased with store location nearer the wing tip.
5. The wing-fuselage-store combination can be made more stable with increased store fineness ratios and locations near the wing tip.

CHAPTER VI

RECOMMENDATIONS

It is recommended that this study be extended to cover the many items omitted which affect the final results. Some of the important items omitted are the following:

1. More exhaustive study of fuselage location and effect of fineness ratio.
2. The effect of store afterbodies.
3. The effects of different airfoil sections for pylons as well as pylon design and span.
4. The interference effects of store-fuselage-wing combinations.
5. The effect of stores on the dynamics of the airplane.
6. The effect of anti-symmetric location and more than two stores.
7. The effect of wing camber and thickness.

These are some of the factors that will vitally affect the results.

APPENDIX

TUNNEL BOUNDARY CORRECTIONS

The wall corrections were made in accordance with NACA Technical Note 2454[2]. The equations used are as follows:

$$\Delta \alpha = 57.3\, C_L \int_0^1 \left(\frac{w}{VC_L}\right)_{\frac{3\bar{c}}{4}} \frac{c_l\, C}{C_L\, C'}\, d\left(\frac{2y}{b}\right)$$

$$\Delta C_D = C_L^{\,2} \int_0^1 \left(\frac{w}{VC_L}\right)_{\frac{\bar{c}}{4}} \frac{c_l\, C}{C_L\, C'}\, d\left(\frac{2y}{b}\right)$$

Wing pitching moment is given in two parts (a) moment resulting from the outward shift in the spanwise center of lift caused by the induced washin along the $\frac{3\bar{c}}{4}$ line and (b) a couple due to the induced camber corresponding to the streamline curvature.

ΔC_L is increment due to induced angle along $\frac{3\bar{c}}{4}$

$$\Delta C_L = 57.3\; a\, C_L \int_0^1 \left(\frac{w}{VC_L}\right)_{\frac{3\bar{c}}{4}} \frac{c_l\, C}{C_L\, C'}\, d\left(\frac{2y}{b}\right)$$

The longitudinal distance of center of pressure X_1 with reference to root end of the $\frac{\bar{c}}{4}$ is:

$$\frac{X_1}{\bar{c}} = \frac{2y}{b}\; \frac{b}{2\bar{c}}\; \tan \Lambda_{\frac{\bar{c}}{4}}$$

$$\Delta C_{M_1} = a C_L \quad \frac{\Delta C_L}{a C_L} \quad \frac{X_1 - X_0}{\bar{c}}$$

$$\Delta C_{M_2} = \frac{\pi \cos\Lambda \frac{\bar{c}}{2} \quad C_L}{4} \int_0^1 \left[\left(\frac{w}{VC_L}\right)_{\frac{3\bar{c}}{4}} - \left(\frac{w}{VC_L}\right)_{\frac{\bar{c}}{4}} \quad \frac{c^2}{\bar{c}\, c'} \right] d\left(\frac{2\,y}{b}\right)$$

$$\Delta C_M = \Delta C_{M_1} + \Delta C_{M_2}$$

All the corrections are added to the uncorrected values. The corrections were calculated by numerical integration of the above equations and are as follows:

$\Delta \alpha$ . . . . $1.32\ C_L$

ΔC_D . . . . $0.0185\ C_L^{\ 2}$

ΔC_M . . . . $0.00772\ C_L$

The Reynolds number was computed using a tunnel turbulence factor of 1.34.

TUNNEL BLOCKING CALCULATIONS

The tunnel blocking corrections were done in accordance with Ref. 7.

$$\varepsilon = \frac{1}{4} \quad \frac{\text{Model frontal Area}}{\text{Test Section Area}}$$

$$q = q_u \quad (1 + 2\varepsilon)$$

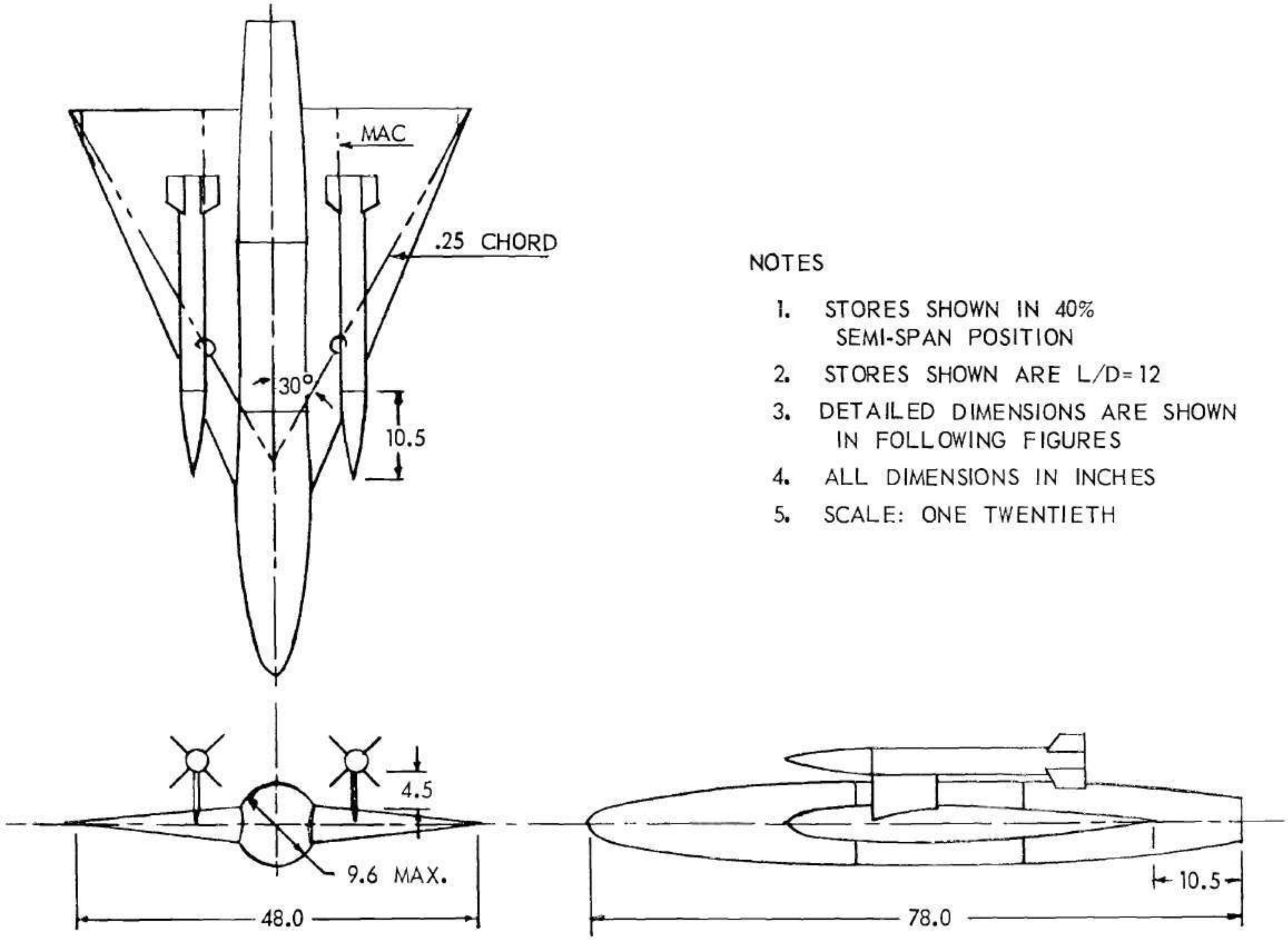
Where q_u corresponds to piezometer setting and is the value at the center line.

q is the value at the center line corrected for blocking.

The $\frac{q \text{ mean}}{q_{\mathcal{C}_L}} = 1.012$ by use of Ref. 8 and integrating the q distribution over the model only.

$$q \text{ mean over the model} = q_u \, (1 + 2\varepsilon) \quad \frac{q \text{ mean}}{q_{\mathcal{C}_L}}$$

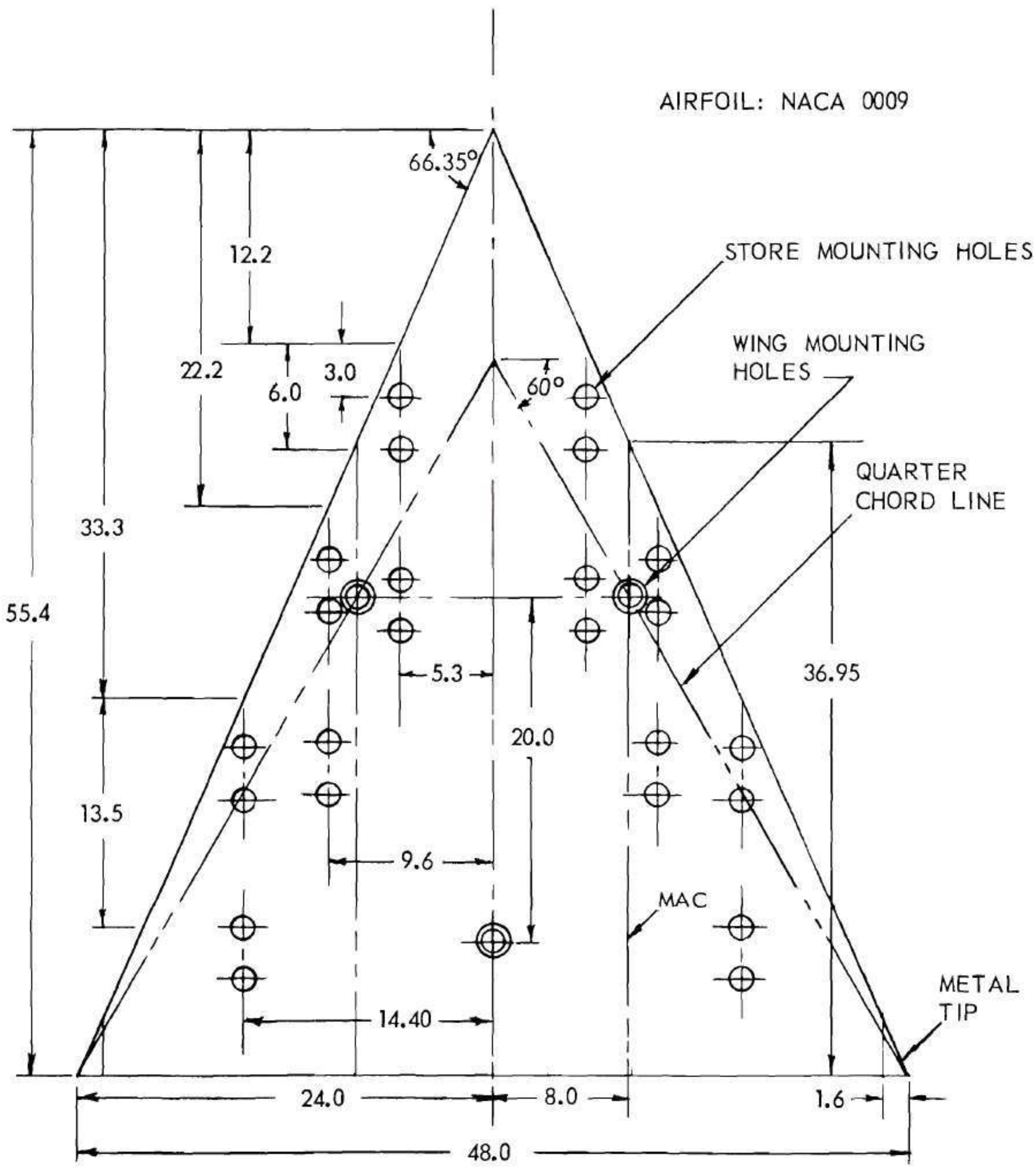
Frontal area of windshields	3.34 sq. ft.
Frontal area of model	1.02 sq. ft.
Frontal area of stores	.147 sq. ft.
Total	4.507 sq. ft.



NOTES

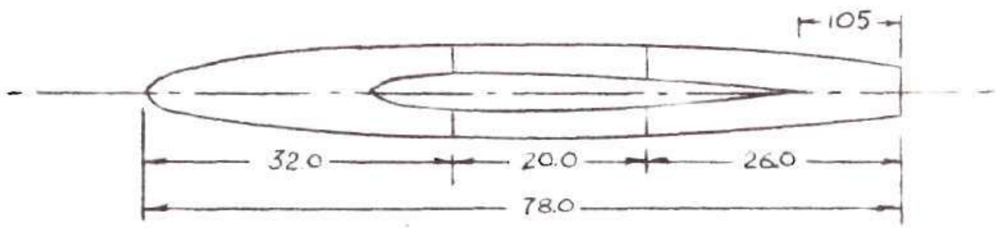
1. STORES SHOWN IN 40% SEMI-SPAN POSITION
2. STORES SHOWN ARE L/D= 12
3. DETAILED DIMENSIONS ARE SHOWN IN FOLLOWING FIGURES
4. ALL DIMENSIONS IN INCHES
5. SCALE: ONE TWENTIETH

Figure 1. Assembled Delta-Wing Model.



ALL DIMENSIONS IN INCHES EXCEPT AS NOTED SCALE: ONE TENTH

Figure 2. Dimensions of Delta.



FUSELAGE – SIDE VIEW

ORDINATES
IN INCHES

STATION	RADIUS
0.	0.
0.4	0.78
0.6	0.94
1.0	1.19
2.0	1.63
4.0	2.25
6.0	2.72
8.0	3.10
12.0	3.70
16.0	4.14
24.0	4.68
32.0	4.79
52.0	4.79
60.0	4.38
68.0	3.64
76.0	2.68
78.0	2.30
L.E. RAD.	0.83

FUSELAGE DIMENSIONS
FIG. 3

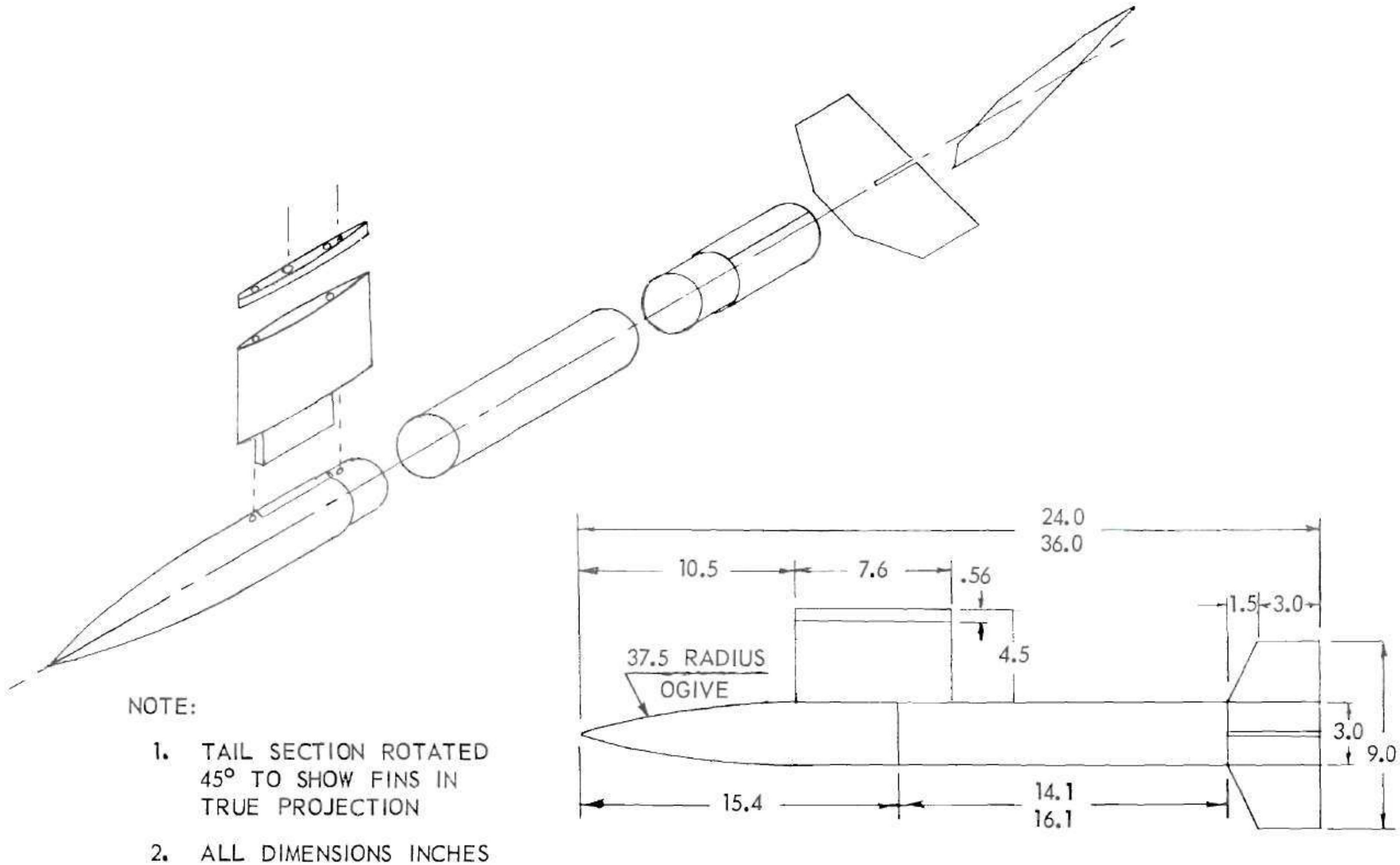


Figure 4. External Store.

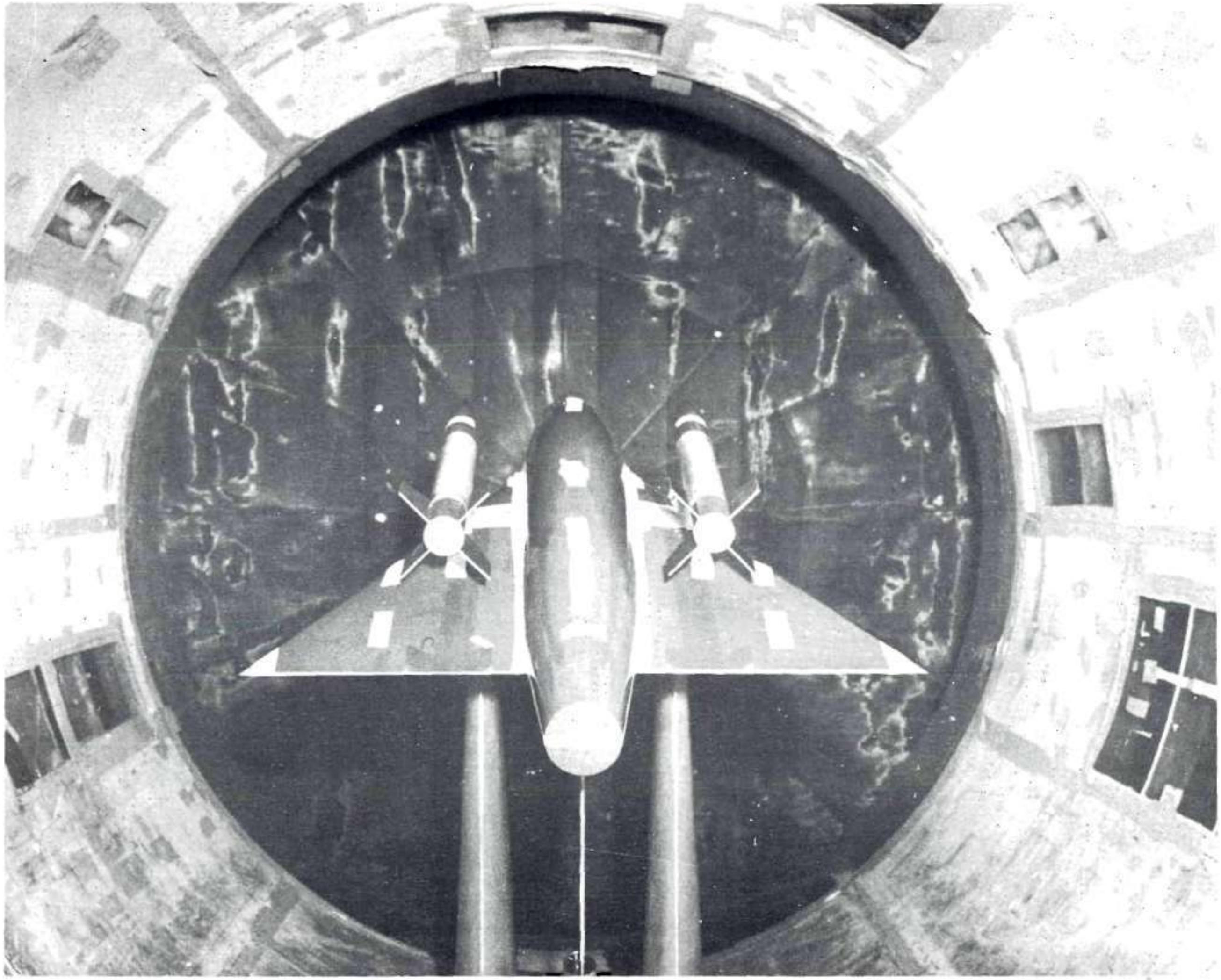
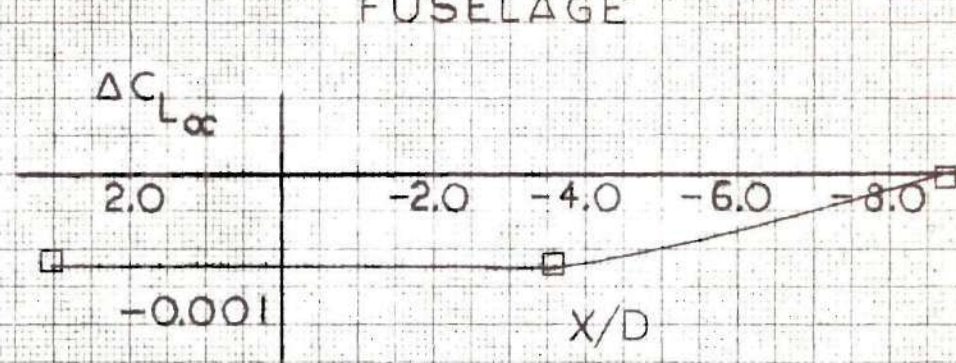


Figure 5. Complete Model Mounted in the Tunnel.



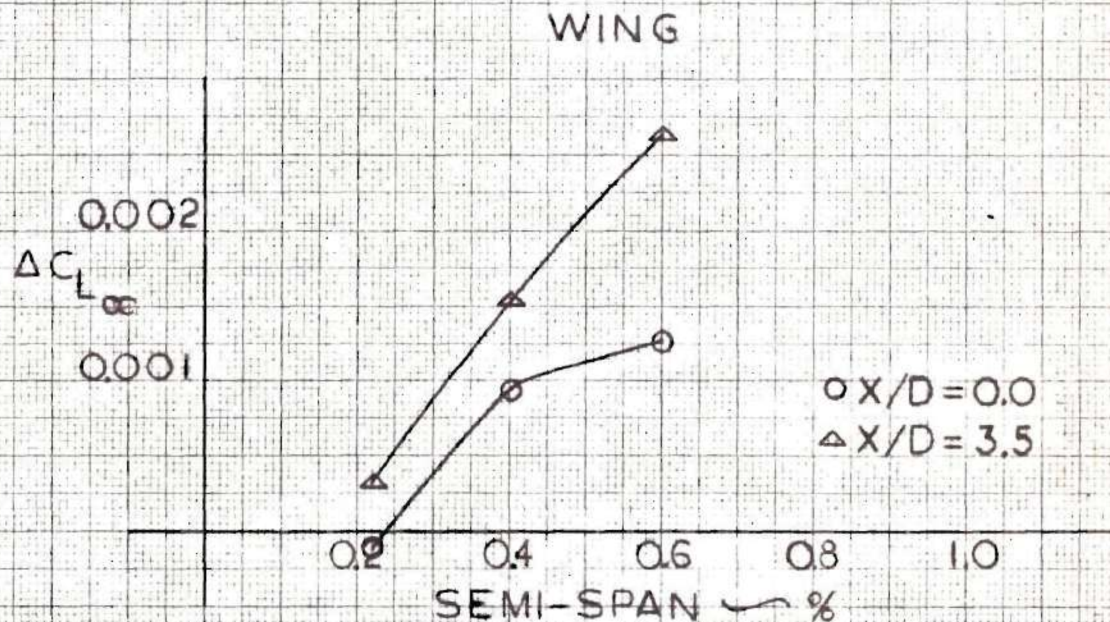


FIG. 8

INCREMENTAL VARIATION OF LIFT CURVE SLOPE

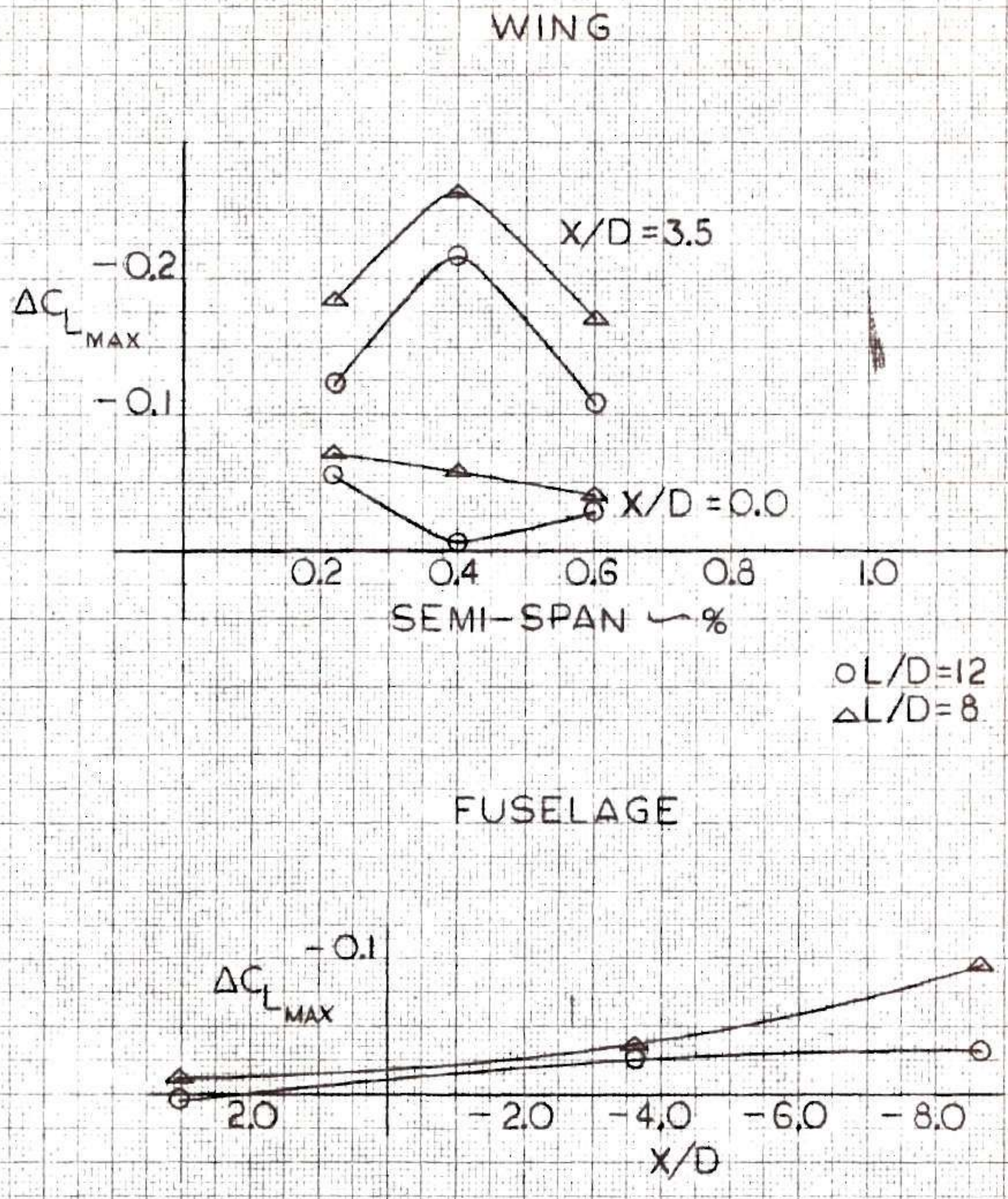


FIG. 9

INCREMENTAL VARIATION
OF MAXIMUM LIET

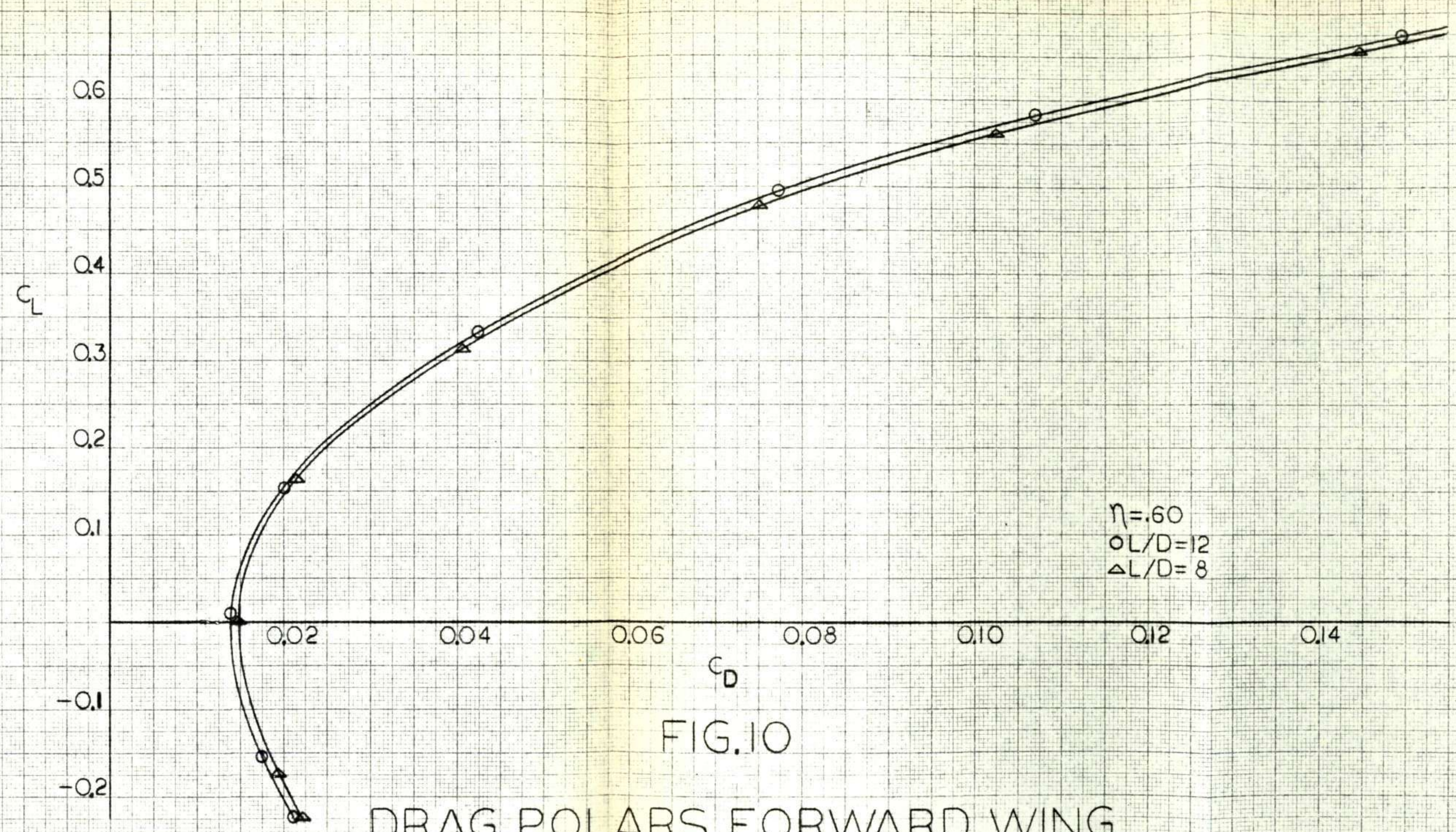


FIG.10

DRAG POLARS, FORWARD WING

X/D = 3.5

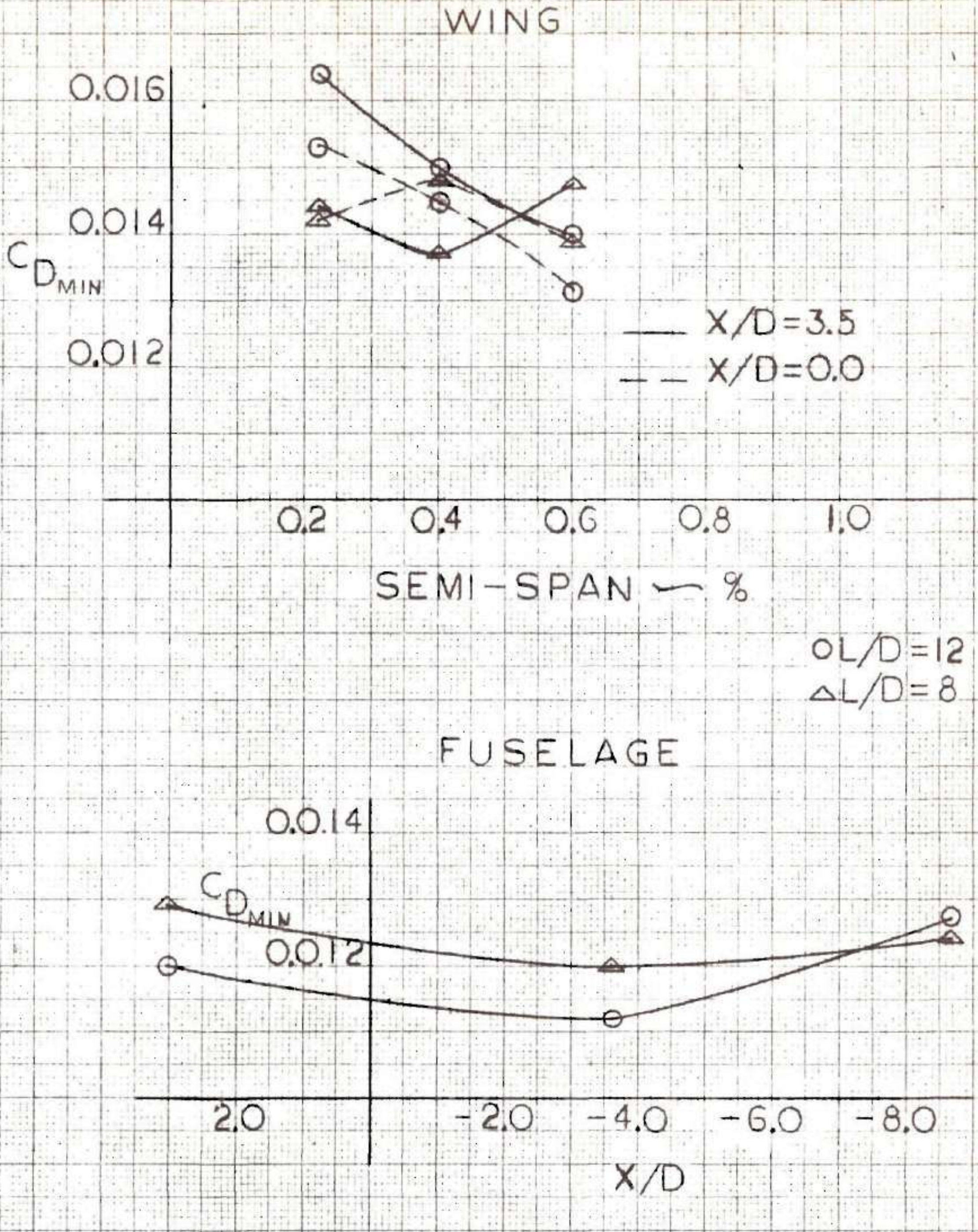


FIG.11

MINIMUM DRAG

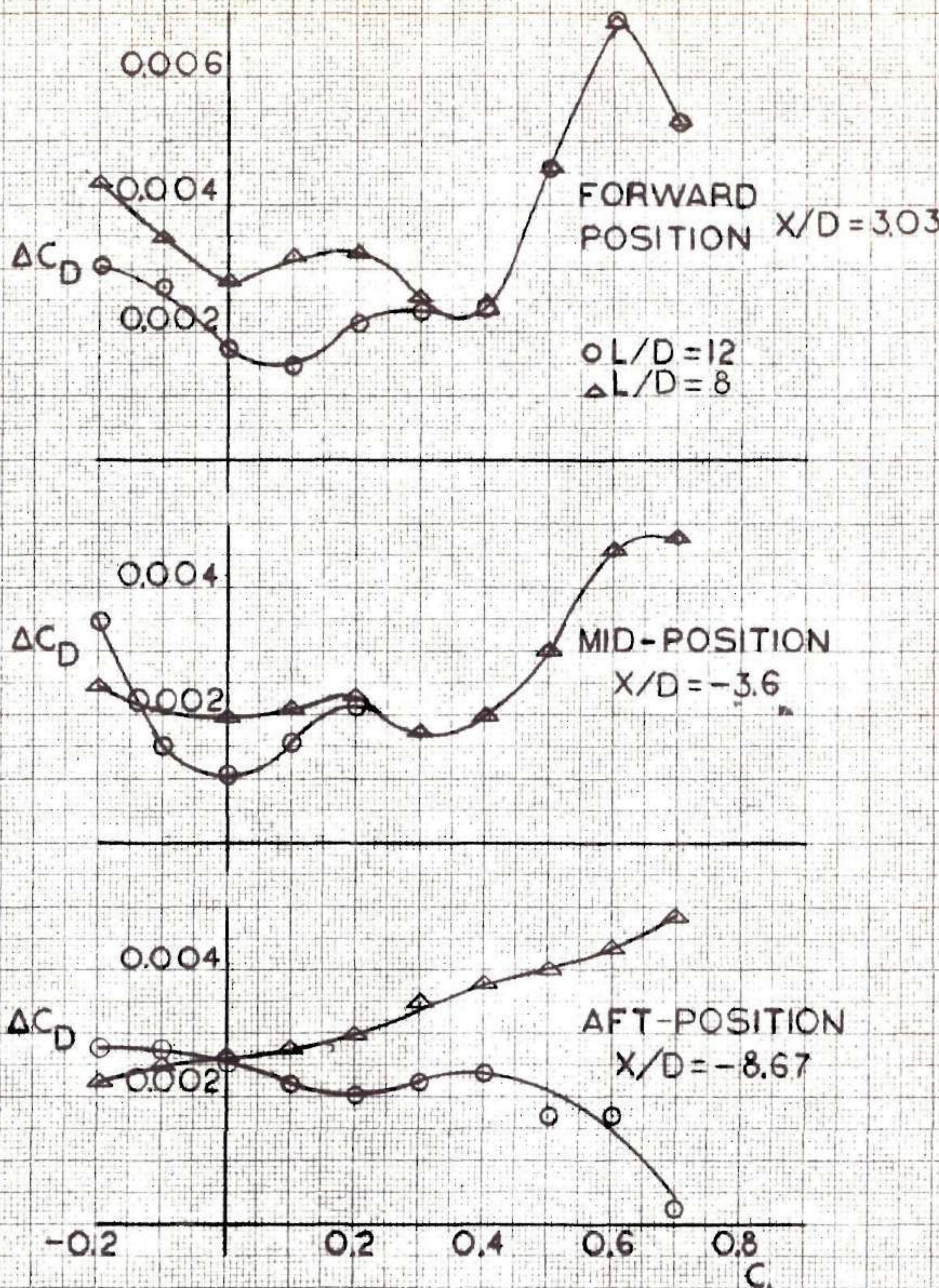


FIG. 12
INCREMENTAL VARIATION
OF DRAG — FUSELAGE

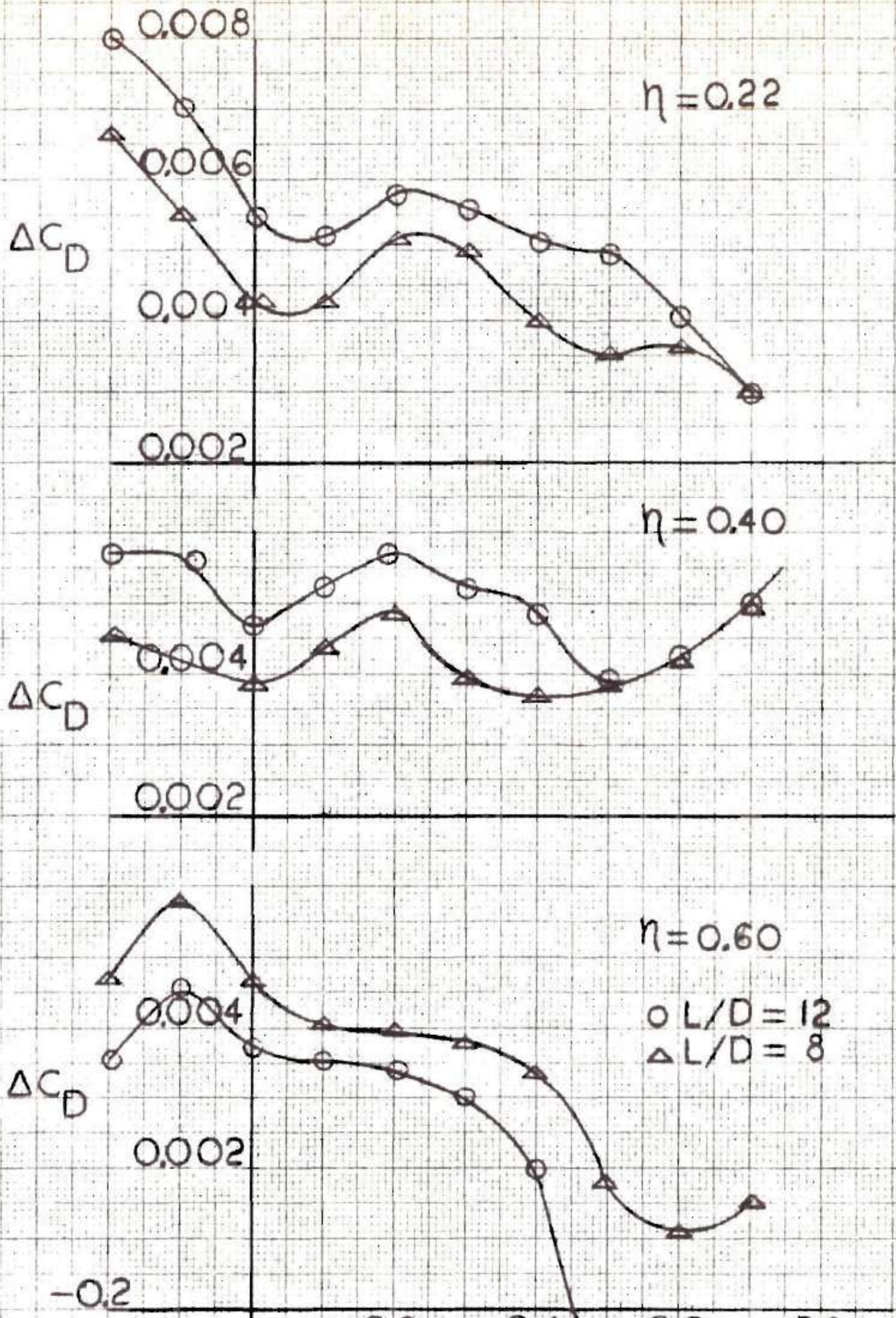


FIG. 13
INCREMENTAL VARIATION
OF DRAG - FORWARD WING
(X/D = 3.5)

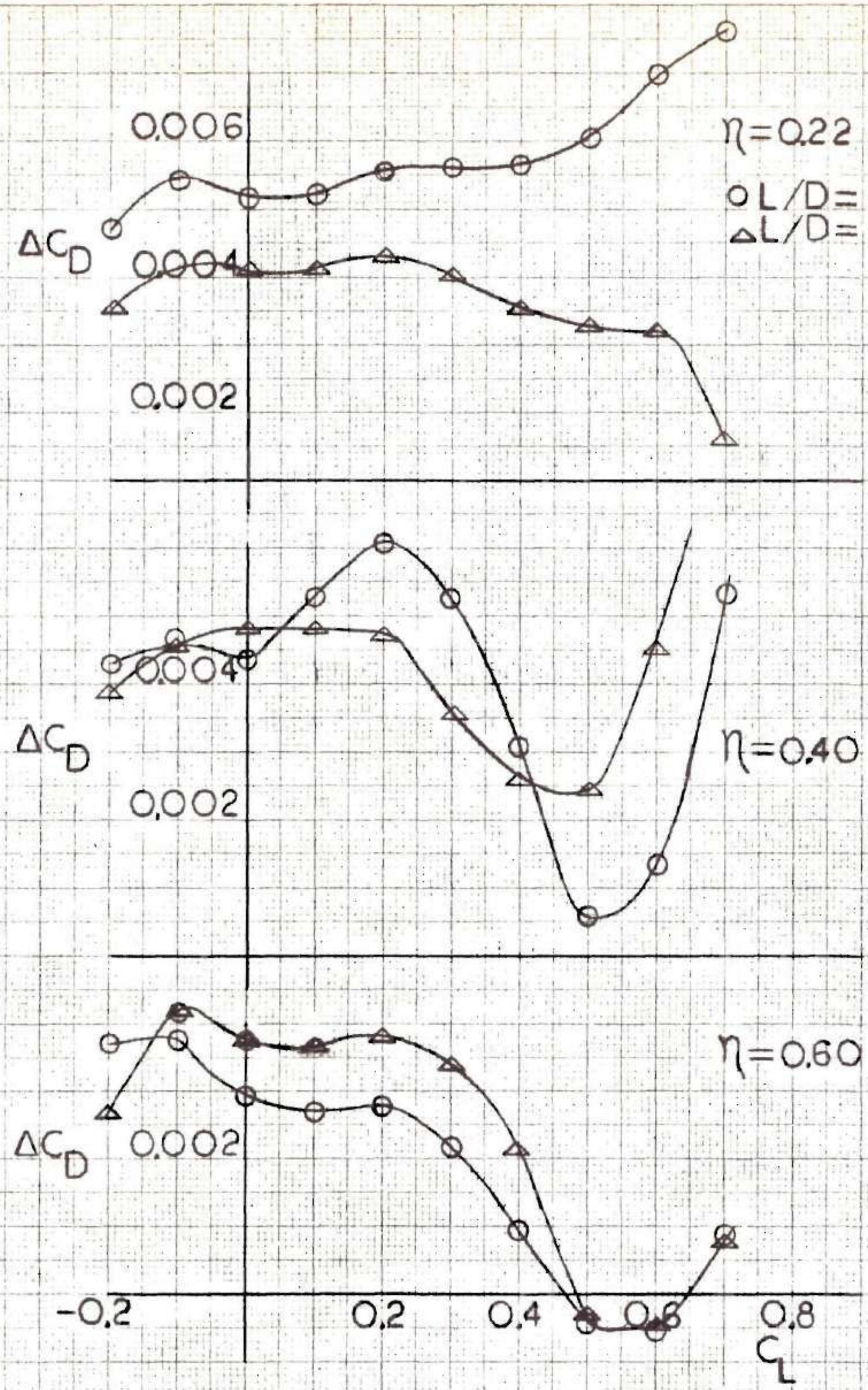


FIG. 14
INCREMENTAL VARIATION
OF DRAG-AFT WING (X/D=0)

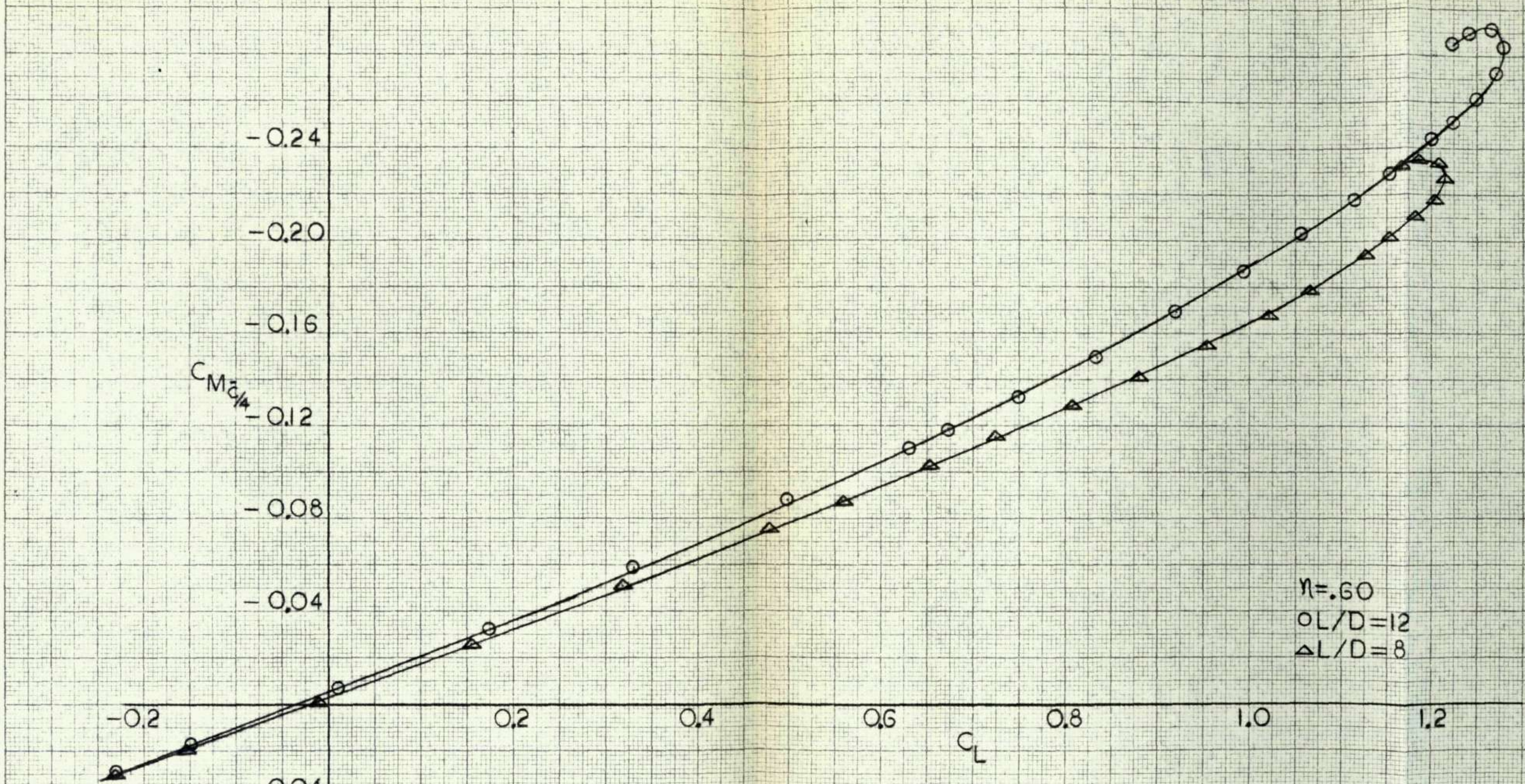


FIG.15

PITCHING MOMENT CURVES
FORWARD WING
X/D = 3.5

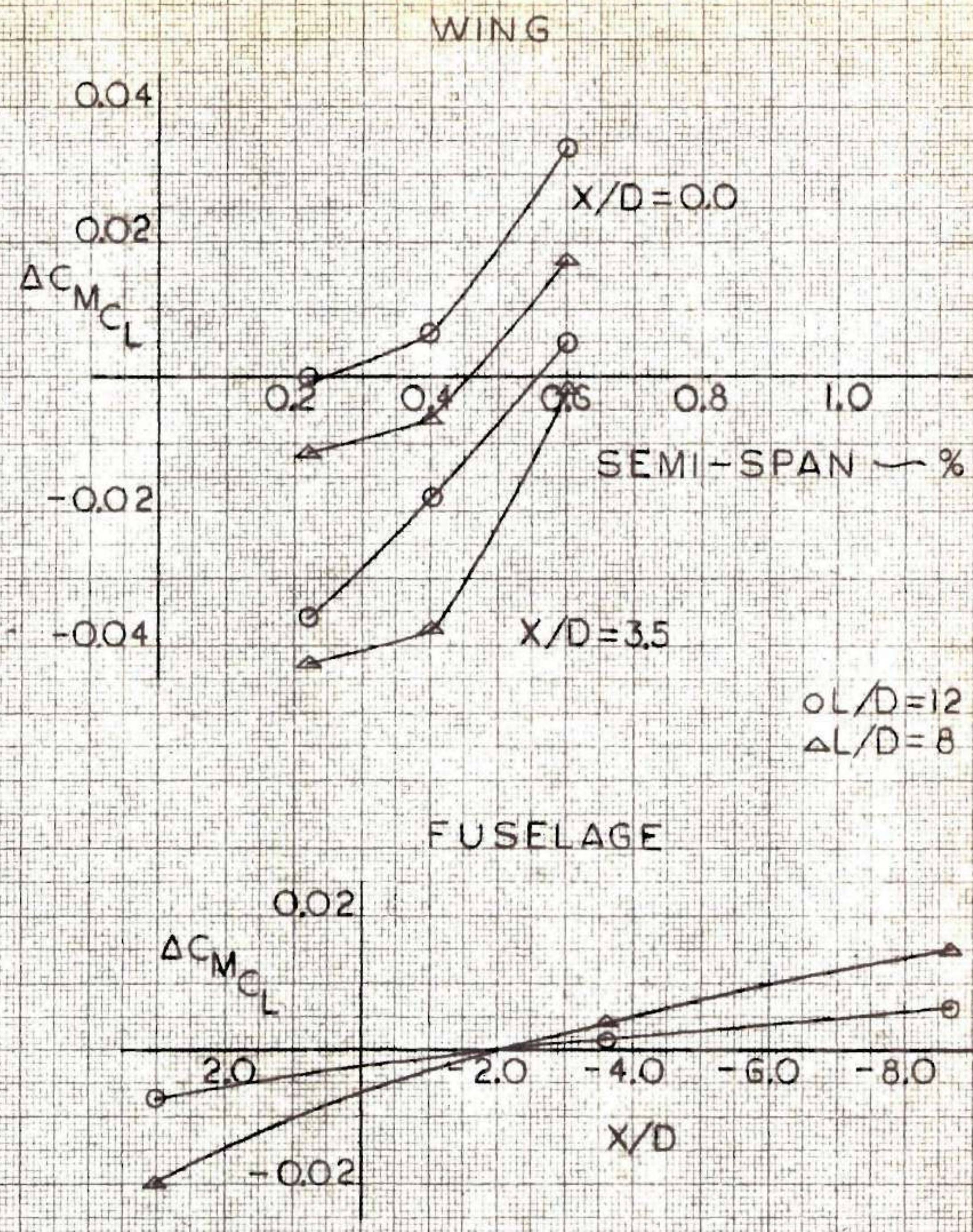


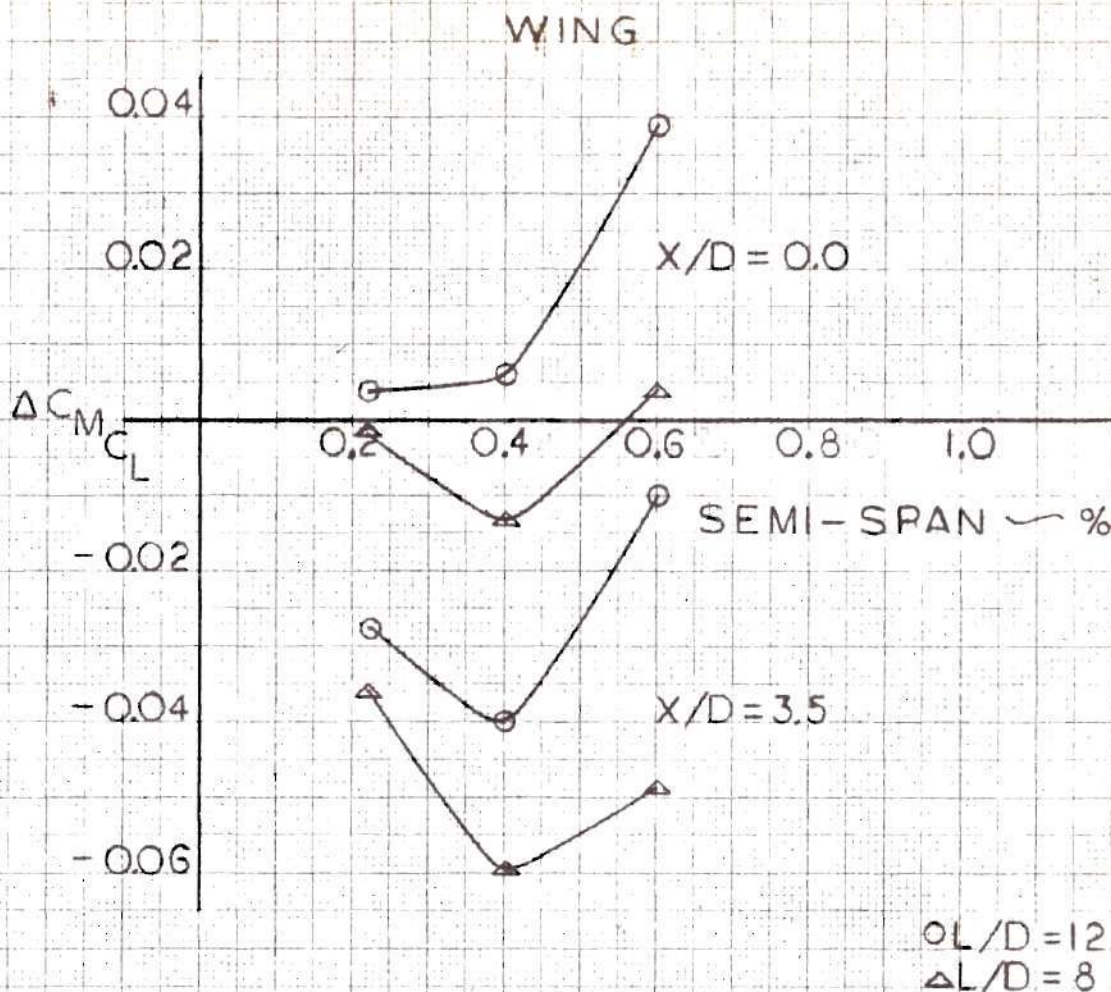
FIG. 16

INCREMENTAL VARIATION

OF

STABILITY DERIVATIVE

$C_L = 0$



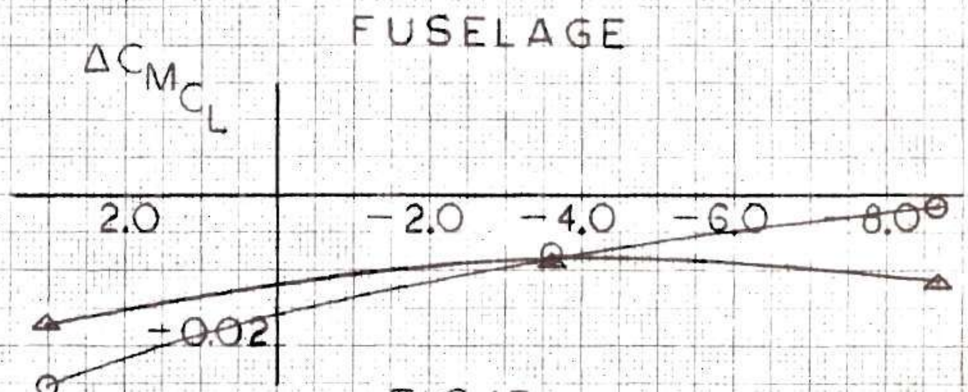


FIG. 17

INCREMENTAL VARIATION
OF
STABILITY DERIVATIVE
$C_L = 0.6$ TO 1.0

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